CHAPTER 5

DETAILED STRUCTURAL ANALYSIS

5-1. Introduction

This chapter prescribes acceptance criteria and describes general procedures for detailed structural analysis of existing buildings. Guidelines are provided for determining the capacity of the existing structure to resist seismic forces. The detailed analysis is performed on buildings that have been selected as a result of the evaluation and/or priorities (chapter 4) established by the approval authority or on buildings as directed by higher authority. The purposes of the detailed structural analysis are to determine if the building satisfies the acceptance criteria or if it requires seismic upgrading, and if it requires seismic upgrading to identify the deficiencies and to recommend alternatives for the upgrading (chapter 6). The methodology for the detailed structural analysis is summarized in figure 5-1.

5-2. Acceptance criteria

The acceptance criteria for the seismic resistance of existing buildings will be essentially as prescribed for the post-yield analysis for EQ-II in paragraph 4-4 of the SDG. If an existing building does not conform to the above criteria some latitude is provided in the following paragraphs in recognition that seismic upgrading is an expensive and disruptive process and it may be more cost-effective to accept an existing building that is marginally deficient rather than to enforce strict adherence to the criteria.

a. Conforming systems and materials. When the lateral force resisting structural systems and materials are in compliance with the requirement of the BDM (Refer to BDM paragraph 3-6 for approved structural systems and to BDM chapters 3, 5, 6, 7, and 8 for material requirements), the earthquake demand represented by the EQ-II response spectra may be reduced by a maximum of 15 percent (i.e., to 0.85 EQ-II) and the drift limitations for EQ-II will remain the same as prescribed in SDG paragraph 4-4*e*(2)(a) (i.e., story drift ratio 0.010 for essential and 0.015 for others).

b. Nonconforming systems and materials. When the lateral force resisting system or the structural materials do not conform to the approved systems and material specifications of the BDM, justification for acceptability of the existing systems and! or materials is required. Requirements for substantiated data are prescribed below. Acceptance of the approval agency is also required.

(1) Structural systems not specified in the BDM and/or SDG (e.g., "nonductile" moment resistant reinforced concrete frames and unreinforced masonry shear walls) require an analytical evaluation report. The report will include data for establishing the capacity of the system to resist seismic loads and justification for the performance of the system satisfying the intent of the BDM and SDG provisions.

(2) Structural materials not satisfying the minimum requirements of the BDM and SDG require an evaluation report. Guidelines are provided in appendix E.

(3) The acceptance criteria for the substantiated noncomplying structural systems and materials are the same as prescribed in paragraph *a*, above, except that the drift will not be allowed to exceed 60 percent of the drift limits prescribed for conforming systems and materials.

c. Alternative acceptance criteria. In lieu of the above acceptance criteria, at the option of the approval authority, the acceptance criteria for the seismic resistance of specific existing buildings, namely other than essential buildings in seismic zones 3 and 4, may be satisfied by conformance with the provisions of the BDM or the Static Code Procedure of appendix C.

5-3. Methodology for the analysis

The detailed structural analysis follows a procedure similar to that used for the preliminary evaluation for determining the capacity of the structure to resist seismic loads, except that the analysis is done in greater detail and with more accuracy in order to increase the reliability of recommendations for acceptability or upgrading. The procedure extends beyond the scope of the preliminary evaluation by identifying deficiencies and evaluating the effects of correcting deficiencies to improve the overall performance capabilities of the building.

a. Document review. Available drawings, calculations, specifications, and other design and/or construction documents will be reviewed in detail for pertinent information that will aid in the detailed structural analysis. Items not covered by the available documents and required to complete a detailed analysis will be investigated during the site inspection.

b. Site inspection. A detailed site examination will be performed to confirm data contained in the available design and construction documents and

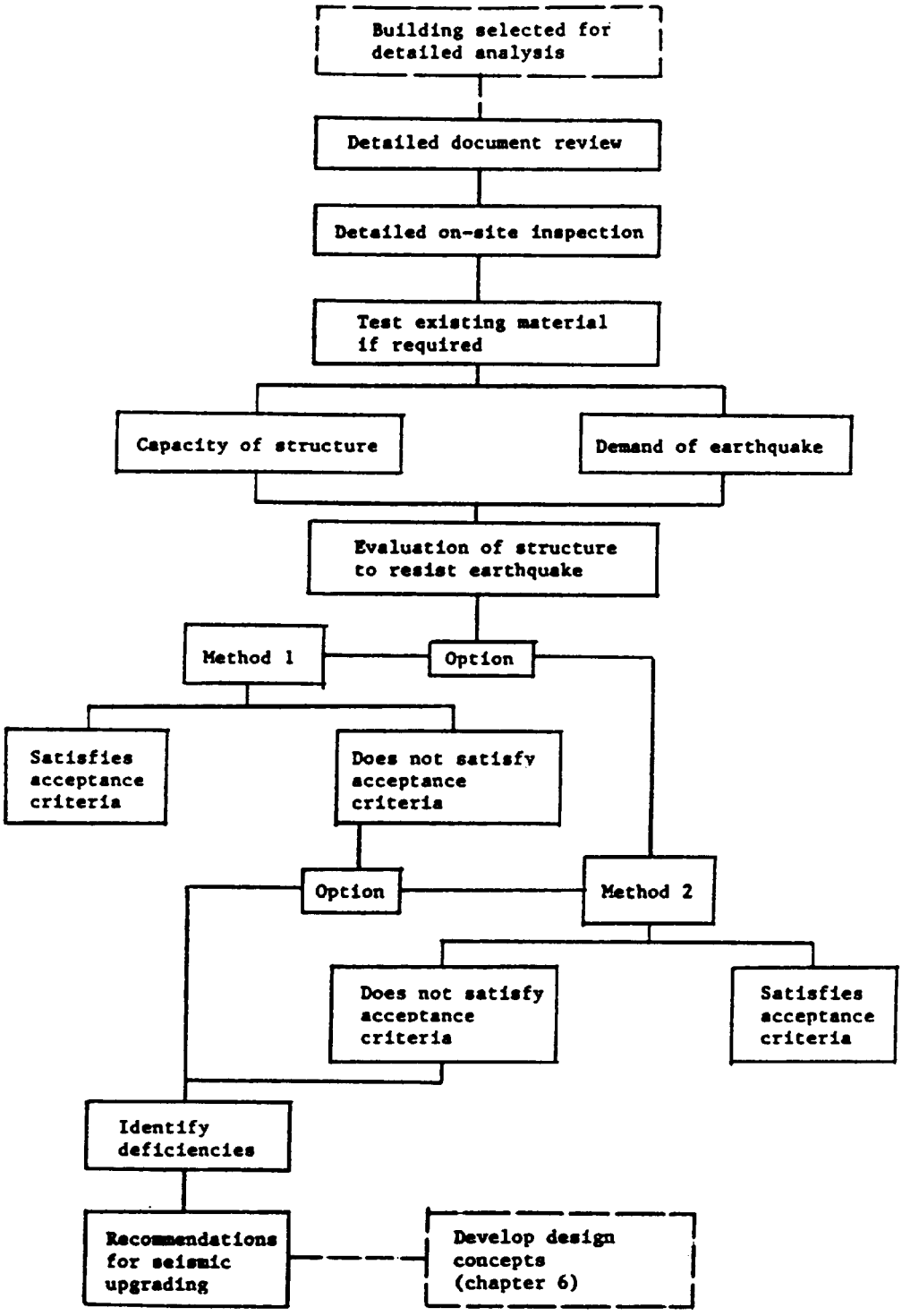

Figure 5–1. Methodology for detailed structural analysis of buildings

the results of any previous inspection and evaluation reports. Special attention will be given to verify the existing lateral force resisting elements and systems (e.g., note any missing bracing members, openings not shown on the drawings, and additions). Testing or special inspection will be made when there is no available data or when as-built conditions are suspect.

c. Testing of existing materials. When economically justified, a testing program may be established to determine the capacity characteristics of nonconforming materials and details, especially when the acceptability of test results can make the

difference between accepting an existing building in an as-is condition as opposed to requiring a costly modification. Structural capacities of existing materials will be determined in accordance with criteria and testing requirements of appendix E.

d. Capacity of the structure. The capacity of the structure to resist lateral forces will be determined in accordance with the guidelines provided in the SDG for new construction with the modifications provided in this manual to cover existing materials and structural systems (Refer to para 5-2 for acceptance criteria).

e. Demands of the earthquake. The structure will be subjected to the demands of EQ-II, as defined in the SDG.

f. Evaluation of structure. The structure will be evaluated by a capacity/demand comparison in accordance with the SDG procedures for designing for EQ-II (refer to SDG paras 4-4 and 5-5), using methods 1 or 2 as described below. Examples of procedures are given in SDG appendix E.

(1) *Method 1:* Elastic analysis procedure (refer to SDG para *4-4c)*. This procedure is used to determine if the existing structure has the required capacity to resist the prescribed earthquake criteria. Table 5-1 is an extended version of SDG table 4-2, inelastic demand ratios.

(a) If the structure meets the acceptance criteria of paragraph 5-2 above and does not have any of the deficiencies listed in paragraph 4-4*c*(5) of the SDG, upgrading is not required.

(b) If the structure does not conform to the acceptance criteria by means of the Method 1 analysis, seismic upgrading will be required unless it can be demonstrated that the building can satisfy the acceptance criteria by means of Method 2, capacity spectrum method.

(2) *Method 2:* Capacity spectrum method (refer to SDG paras 4-4*d* and 5-5*b*). This procedure is used to compare to earthquake demand as represented by an appropriate response spectrum with the structural capacity as represented by a capacity spectrum with accelerations, S_a, the building can resist when it has fundamental periods, T.

(a) If the structure conforms to the acceptance criteria of paragraph 5-2 with the Method 2 analysis, upgrading is not required.

(b) If the structure does not conform to the acceptance criteria with the Method 2 analysis, upgrading will be required.

g. Identify deficiencies for structures that are selected for seismic upgrading. The results of the detailed structural analysis from Method 1 or Method 2 will be used to identify the structural deficiencies.

(1) For Method 1, in most cases, structural deficiencies will be identified as those that exceed the allowable inelastic demand ratios given in table 5-I, which is an extended version of table 4-2 of the SDG. The results of the Method 1 analysis will also be evaluated to identify other deficiencies indicated in paragraph 4-4*c*(5) of the SDG.

(2) For Method 2, in most cases, structural deficiencies will be identified as those members that limit the capacity of the structure below the level required by the earthquake demand because of inelastic yielding or rotation. However, care should be exercised in the determination of the structural capacities to confirm that the possibility of the other deficiencies indicated in paragraph 4-4*c*(5) of the SDG have been properly considered in the determination of the structural capacity.

(3) For both Method 1 and Method 2, supplementary structural analyses, as described in the BDM for new construction, must be performed to determine the structural adequacy of an existing building or to identify possible deficiencies. These analyses include:

(a) Evaluation of foundations for vertical bearing and the transfer of horizontal forces to the soil.

(b) Evaluation of floor and roof diaphragms for shear capacity and shear transfer to vertical resisting members. Also adequacy of diaphragm chords and collector members.

(c) Out-of-plane bending of vertical walls and piers, including anchorage and support at floor and roof levels.

(d) Adequacy of support and anchorage of equipment, piping, and nonstructural elements as described in chapter 9.

(e) Adequacy of bracing or lateral supports to preclude local buckling of steel members.

(f) Check of P-delta effects (see SDG para 5-5*d* for additional guidance), local torsion and other secondary stresses.

5-4. Recommendations

On the basis of the detailed structural analysis results, recommend alternatives for seismic upgrading.

Table 5–1. Inelastic demand ratios for existing buildings. (Sheet 1 of 2)

Building System	Element	Essential	High Risk	Others
a. Systems conforming to BDM requirements.				
Steel				
DMRSF	Beams	2.0	2.5	3.0
	Columns*	1.25	1.5	1.75
Braced Frames	Beams	1.5	1.75	2.0
	Columns*	1.25	1.5	1.75
	Diag. Braces**	1.25	1.5	1.5
	K-Braces***	1.0	1.25	1.25
	Connections	1.0	1.25	1.25
Tie Rods	Tension only	1.0	1.1	1.25
Concrete				
DMRSF	Beams	2.0	2.5	3.0
	Columns*	1.25	1.5	1.75
Walls:				
(1) Single curtain	Shear	1.1	1.25	1.5
of reinforcing	Flexure	1.5	1.75	2.0
(2) Double curtain	Shear	1.25	1.5	1.75
of reinforcing	Flexure	2.0	2.5	3.0
Diaphragms	Shear	1.25	1.5	1.75
	Flexure	1.5	1.75	2.0
Masonry Walls	Shear	1.1	1.25	1.5
	Flexure	1.5	1.75	2.0
Wood	Trusses	1.5	1.75	2.0
	Columns*	1.25	1.5	1.75
	Shear Walls and Diaphragms	2.0	2.50	3.0
	Connections (other than nails)	1.25	1.50	2.0

*In no case will axial loads exceed the elastic buckling capacity.
**Full panel diagonal braces with equal number acting in tension and compression for applied lateral loads.
***K-bracing and other concentric bracing systems that depend on compression diagonal to provide vertical reaction for tension diagonal.

Table 5–1. Inelastic demand ratios for existing buildings. (Sheet 2 of 2)

Building System	Element	Essential	High Risk	Others
b. Systems not conforming to BDM requirements.+				
Concrete Frames	Beams	1.25	1.5	1.75
	Columns*	1.0	1.25	1.25
Unreinforced Concrete Walls	Shear	1.0	1.1	1.25
	Flexure	1.0	1.0	1.0
Unreinforced Masonry Walls	Shear	1.0	1.1	1.25
	Flexure	1.0	1.0	1.0

*In no case will axial loads exceed the elastic buckling capacity.
+See also paragraph 5-2b for additional acceptance criteria for nonconforming structural systems.

Sheet 2 of 2